SJR-WARMF 2008 and 2012 Error Analysis

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List of Acronyms

alt.	Alternate
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BOD	Biochemical Oxygen Demand
CALFED	Collaboration Among State and Federal Agencies to Improve California's Water Supply
CBOD	Carbonaceous Biochemical Oxygen Demand
CCID	Central California Irrigation District
chl	Chlorophyll-a
CUWA	California Urban Water Agencies
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DWSC	Deep Water Ship Channel
EERP	Ecological Engineering Research Program
EPA	United States Environmental Protection Agency
kg d^{-1}	Kilograms per day
lb d^{-1}	Pounds per day
MODFLOW	Modular Finite-Difference Flow Model
MWD	Metropolitan Water District of Southern California
NBOD	Nitrogenous Biochemical Oxygen Demand
NO_3-N	Dissolved Nitrate Plus Nitrite as Nitrogen
Org N	Organic Nitrogen
PO_4-P	Dissolved Orthophosphate as Phosphorus
R^2	Coefficient of Determination
SJR	San Joaquin River
Std. Dev.	Standard Deviation
TAN	Total Ammonia Plus Ammonium Nitrogen
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USBR	United States Bureau of Reclamation
WARMF	Watershed Analysis Risk Management Framework

Introduction

The Watershed Analysis Risk Management Framework model of the upstream San Joaquin River (SJR-WARMF)was developed by Systech Water Resources to support the development of a total maximum daily load (TMDL) for dissolved oxygen (DO) in the Stockton Deep Water Ship Channel (DWSC). WARMF consists of connected catchments and river segments to represent the SJR upstream of Old River. The model simulates watershed hydrology, land use, and river flow in the upstream SJR watershed to calculate water quality for use as input to the Link-Node model, which simulates the tidal estuary region of the SJR between Old River and Rindge Tract to calculate dissolved oxygen in the Stockton DWSC (Herr, Chen, and van Werkhoven 2008). Two different versions of WARMF were utilized in this effort. SJR-WARMF 2008 was developed as part of the up-stream study of the SJR under the Collaboration Among State and Federal Agencies to Improve California's Water Supply (CALFED) (Herr, Chen, and van Werkhoven 2008) while SJR-WARMF 2012 was developed through a series of independent projects between 2008 and 2012 sponsored by the Central Valley Salinity Alternatives for Long Term Sustainability (CV-SALTS), the United States Bureau of Reclamation (USBR), the California Urban Water Agencies (CUWA), and the Metropolitan Water District of Southern California (MWD) (Larry Walker and Associates et al. 2010; USBR 2012a; USBR 2012b; Systech 2011; Systech 2012).

The objective of this analysis was to compare the utility of the WARMF 2008 and 2012 models for simulating the upper SJR watershed in support of compliance and maintenance of dissolved oxygen in the Stockton Deep Water Ship Channel (DWSC). The domain, complexity, inputs, and functionality of each model is presented along with a discussion of the advantages and disadvantages of each model. A comparison of the mean relative and absolute error of each model with respect to observed grab sample data for nitrate, ammonia, total nitrogen, phosphate, total phosphorus, biochemical oxygen demand, total dissolved solids, and phytoplankton is presented to assess the accuracy and precision of each model at Vernalis. Lastly, recommendations for the future development of both models are presented.

Materials and Methods

Observed Loads

The grab samples used to calculate observed loads for the error analysis were collected in the SJR at Vernalis between 2005 and 2007 in a previous Ecological Engineering Research Program (EERP) study (Stubblefield et al. 2013). Total nitrogen (TN), total ammonia plus ammonium nitrogen (TAN), dissolved nitrate plus nitrite as nitrogen (NO_3-N), dissolved orthophosphate as phosphorus (PO_4-P), total phosphorus (TP), total dissolved solids (TDS), biochemical oxygen demand (BOD), total phytoplankton as chlorophyll-a (chl), and dissolved organic carbon (DOC) grab samples were taken by EERP. Loads were computed by multiplying the daily average flow by the constituent concentration. Organic Nitrogen (Org N) loads were calculated by subtracting NO_3-N and TAN loads from TN loads. Note that the grab sample BOD includes both carbonaceous BOD (CBOD) and nitrogenous BOD (NBOD) while WARMF 2008 and 2012 only simulates CBOD since it was assumed that NBOD was small enough to be neglected (Herr, personal communication). For the purposes of this analysis, both observed and simulated loads are labeled as BOD when comparisons to each other are presented.

WARMF 2008 Model

Model Configuration

Catchments were delineated based on the United States Environmental Protection Agency (EPA) Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). Land use, meteorology, air quality, point source discharge, land application, irrigation water, and boundary inflow data was obtained from available data sources. Calibration parameters included reaction rates for evaporation, phytoplankton, BOD decay, organic carbon decay, nitrification, denitrification, sulfate reduction, particle settling; initial conditions for soil layers and soil erosivity, and soil pore water concentrations; and river adsorption isotherms. WARMF was calibrated from October 1, 1999 through September 30, 2005 and verified using new data from October 1, 2005 through September 30, 2007. This version of WARMF was completed in May of 2008 (Herr, Chen, and van Werkhoven 2008). An additional update was performed in 2008 for a project with the United States Bureau of Reclamation (USBR) so that the upper SJR watershed between Friant Dam and Bear Creek could be simulated separately (Systech 2011).

The model domain of WARMF 2008 is shown in Figure 1. Thirteen different land uses, consisting of seven types of land cover, four types of agriculture, and two types of urban land, are represented. Each land use utilizes different areal land application rates for constituents. In catchments where agriculture is present, only orchard and cropland / pasture irrigation is modeled. Not all of the rivers and catchments in the model are utilized. Only 32 catchments have either irrigation sources or receive precipitation; the remaining catchments have no flow sources and have a precipitation weighting factor of zero, making them incapable of generating runoff or groundwater flow. Instead, this model utilizes observed flow and water quality data from the 1980's through September 30, 2007 as inputs for the Delta Mendota Canal, Hospital Creek, Ingram Creek, Del Puerto Creek, Orestimba Creek, Los Banos Creek, Mud Slough, Salt Slough, the Merced River, the Tuolumne River, and the Stanislaus River. In addition, a boundary inflow file is specified in the SJR upstream of Lander Avenue and no hydrologic connection exists between the SJR upstream of this point and the study area.

Model Simulation and Load Computation

A simulation was conducted by copying a baseline scenario included in the model installation and running the model using the default simulation time period of October 1, 1999 through September 30, 2007 and a time step of 6 hours. The time step was chosen to enable simulation of phytoplankton dynamics, which could not be done on a daily time step (Herr, Chen, and van Werkhoven 2008). Results at Vernalis (River ID 184) were exported for flow, NO_3-N, TAN, TN, PO_4-P, TP, DOC, CBOD, TDS, and total phytoplankton (chl). Loads at Vernalis were calculated by multiplying the constituent concentration by the flow.

WARMF 2012 Model

Model Configuration

The update areas in WARMF 2012 are shown in Figure 2. The eastern model domain was updated during the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) Salt and Nitrate Pilot Implementation Study in 2010. Catchments in the eastern model domain were defined by drainage boundaries and then adapted to follow groundwater model cells in the modular finite-difference flow model (MODFLOW), an independent groundwater model used in conjunction with WARMF. MODFLOW was used to calculate groundwater pumping inputs for catchments in WARMF. Land use data, land application rates, irrigation rates, soil parameters, and point source data was updated within the study region and WARMF was calibrated for the 1998-2007 water years to flow and water quality monitoring data at Vernalis (Larry Walker Associates et al. 2010).

In the Westside Salt Assessment by the USBR (2012a), a project similar to the CV-SALTS Salt and Nitrate Pilot Implementation Study, the western domain of the WARMF model was updated and expanded to include headwater catchments that contribute to winter runoff in the western streams, matching the water-district based catchment delineations used in the Westside Simulation Model (USBR 2012b). Land use, reaction rate, land application rate, meteorology, and irrigation data was updated; groundwater pumping was also included in the western region as with the CV-SALTS Salt and Nitrate Pilot Implementation Study, but utilized observed data and estimations based on streamflow instead of simulated results from MODFLOW (USBR 2011; USBR 2012a; USBR 2012b).

Two new tributary inflow files were added to represent water exchanges between the Delta Mendota Canal, and both Mendota Pool and the O'Neil Forebay (Systech 2011). Model calibration focused on electrical conductivity (as specific conductance, Herr personal communication and Hanlon personal communication) and NO_3-N from October 1, 1999 through September 30, 2007 in the SJR at Vernalis, Salt Slough, San Luis Drain, Mud Slough, Los Banos Creek, Orestimba Creek, Del Puerto Creek, and the SJR at Crows Landing. Calibration parameters included land use system coefficients, soil coefficients and initial conditions, catchment reaction rates, river reaction rates, river adsorption isotherms, land application rates, and irrigation water quality. Two different scenarios were utilized with different modeling assumptions, with the second scenario increasing the amount of irrigation water applied when excess irrigation water supply exists for a subwatershed due to possible underestimates of crop demand in the first scenario (USBR 2012a; USBR 2012b).

After the CV-SALTS and USBR updates to WARMF between 2008 and 2010, the California Urban Water Agencies (CUWA) and the Central Valley Drinking Water Policy Work Group used WARMF to analyze nutrients, salt, and organic carbon for drinking water quality in 2011. New land use data, classifications, irrigation rates and water sources, and point sources for catchments between the SJR at Lander Avenue and Vernalis were added or merged with existing data when applicable. Additional meteorology data from 1975 through 1991 and 1997 through 2007 was added throughout the model. Seven additional boundary inflow files were added to the Stanislaus River at Ripon, Tuolumne River at Modesto, Merced River at Stevinson, the SJR at

Lander Avenue, the upper and lower Delta Mendota Canal, and Mendota Pool from Fresno Slough to enable simulations from 1975 through 1991. Flow, electrical conductivity, DOC and total organic carbon, TAN, NO_3-N, and TP calibration and error analysis was performed for the 2000 through 2007 at the SJR near Stevinson, Crows Landing, and Vernalis (Systech 2011).

Later in 2011, Systech updated WARMF for forecasting flow and turbidity at the Banks Pumping Plant for the 2012 water year for MWD to assist the plant operators with minimizing incidental take of salmon and smelt. The boundary inflow file for the SJR upstream of Lander Avenue was removed to allow flow simulations from the Lander Avenue watershed and the SJR below Friant Dam. Additional suspended sediment, and turbidity data from the 2010 water year was included and used to hindcast and forecast turbidity outside of the model. The 2010 water year data for flow, turbidity, and suspended sediment was used to calibrate WARMF for the SJR at Lander Avenue and at Vernalis by modifying river bed scour rates and clay and silt particle settling velocities (Systech 2012).

The latest documented update to WARMF is the Focused Agricultural Drainage Study for the SJR Dissolved Oxygen Total Maximum Daily Load Project, where Systech and EERP improved the catchment delineations for the Orestimba Creek subwatershed to gain a better understanding of how changes to agricultural land management practices affect nutrients in Orestimba Creek (Systech 2013). The catchment delineations were revised based on aerial photographs. Irrigation sources were updated and new river element representing the Central California Irrigation District (CCID) main canal was included to account for source water mixing and include small canal spills in Orestimba Creek during the summer. Groundwater recharge was also included based on the results of a water balance analysis. Model calibration was conducted from 2000 to 2007.

The model domain for WARMF 2012 is shown in Figure 3. WARMF 2012 included 41 different land uses, consisting of nine types of land cover, 26 types of agricultural land, with more types of crop irrigation represented, and 6 types of urban land, including paved areas. With the larger model domain, decreased use of boundary inflow files, and increase in the number and complexity of processes simulated, this model was designed to be more mechanistic than the WARMF 2008 model, thus increasing the need for calibration and validation to confirm its predictive capabilities. Despite the mechanistic nature of the model, this model also requires at least the same amount of data collection as WARMF 2008, if not more, so that individual tributaries can be calibrated and validated.

Model Simulation and Load Computation

In addition, the WARMF 2012 model engine was also updated to include the Gowdy Output post-processor, a tool that tracks the flow and mass load at a downstream location to individual upstream sources along a river reach. Systech applied the Gowdy Output applied along the SJR from the site near Stevinson (River ID 752) to Vernalis (River ID 184) for the WARMF 2012 baseline scenario run using a 6-hour time step for the time period from October 1, 2004 through September 30, 2012 and sent load results at Vernalis to EERP for analysis. The Gowdy Output results were collected for NO_3-N, TAN, TN, PO_4-P, TP, DOC, CBOD, TDS, and total phytoplankton as (chl). For each day, loads from each of the 59 river points along the San

Joaquin River were added together to obtain the total load at Vernalis. Further documentation of the Gowdy Output is discussed in Weissmann et al. (2013a).

Error Analysis

For a model to be effective as a tool for decision-making, it must have desirable accuracy and precision. Accuracy describes the tendency of the model to underpredict or overpredict the observed data while precision describes the ability of the model to match the pattern of the data (Figure 4). To assess the accuracy and precision of the WARMF 2008 and WARMF 2012 models, the mean relative and absolute error was calculated using the calculated loads from the WARMF 2008 model, the Gowdy Output from the WARMF 2012 model, and calculated loads from the observed grab sample data. The mean relative error, a measure of model accuracy, can be calculated using

$$E_{\text{rel}} = \frac{1}{n}\sum_{i=1}^{n}(x_i - c_i) \tag{1}$$

$$\%E_{\text{rel}} = \frac{E_{\text{rel}}}{\bar{c}} \tag{2}$$

where E_{rel} is the mean relative error, $\%E_{\text{rel}}$ is the percent mean relative error, n is the number of measurements, x_i is the simulated load, c_i is the load calculated from observed data, and $\bar{c}$ is the mean of all of the loads calculated from observed data. The mean absolute error, a measure of model precision, is calculated using

$$E_{\text{abs}} = \frac{1}{n}\sum_{i=1}^{n}|x_i - c_i| \tag{3}$$

$$\%E_{\text{abs}} = \frac{E_{\text{abs}}}{\bar{c}} \tag{4}$$

where E_{abs} is the mean absolute error and $\%E_{\text{abs}}$ is the percent mean absolute error.

Results and Discussion

Statistical Analysis

The coefficient of determination values (R^2) calculated for load output from each model version and loads calculated from the grab sample data are presented in Table 1. Both models have correlation coefficients greater than 0.8 for Org N, PO_4-P, TP, and DOC with respect to the observed data; between 0.5 and 0.8 for TAN, BOD, total phytoplankton (chl), and TDS; and less than 0.5 for NO_3-N. WARMF 2012 has higher correlation coefficients for TAN and TN while WARMF 2008 has higher correlation coefficients for the remaining constituents, suggesting that WARMF 2008 has a better linear fit to observed grab sample data. Summary statistics for loads calculated from observed values, loads the Gowdy Output in WARMF 2012, and loads calculated from concentration and flow in WARMF 2008 are presented in Table 2. The mean observed BOD load is about double the individually simulated CBOD for WARMF 2012 and WARMF 2008, suggesting that both models tend to under-predict BOD. The maximum observed BOD load is 237,855 kg d^{-1} and the maximum simulated BOD load in WARMF 2012 is 216,543 kg d^{-1} while WARMF 2008 predicts a maximum CBOD of 114,401 kg d^{-1}, which is about half of the maximum observed load and load predicted by WARMF 2012. The minimum PO_4-P load predicted by WARMF 2012 is -38 kg d^{-1} the negative sign indicates that the minimum PO_4-P load is actually a net diversion instead of a net discharge.

Error Analysis

The mean relative and absolute error for loads calculated using the 2012 and 2008 model are shown in Table 3. Based on the mean relative error values and percentages, the 2012 model has improved accuracy over the 2008 model when using simulated flow and concentration values to predict ammonia and total nitrogen loads, while nitrate, organic nitrogen, and chlorophyll-a loads calculated using the 2008 model are more accurate. Both models have about the same accuracy when flow and concentration values are used to calculate BOD and TDS loads. Based on the mean precision values and percentages from Table 3, the 2012 model has better precision when using simulated values to calculate TAN while NO_3-N, Org N, TDS, and total phytoplankton loads (chl) calculated using the results of the 2008 model are more precise. TN and BOD loads calculated using results from both models have about the same precision.

Figures 5 through 24 show box plots of the relative error and absolute error values for both the 2012 and 2008 model; the gray line represents the mean relative error and absolute error for the entire 2005-2007 year period where applicable, while the blue line represents the mean relative error and absolute error values for each year and month where applicable. The smaller the errors, the closer the mean error is to zero. Constituents with smaller interquartile ranges and outliers spaced closer to the median have calculated errors that are more consistent for that particular year or month. Based on the sum of mean relative and absolute error percentages by year (Table 4) from 2005-2007, both models tended to have higher mean relative and absolute errors in 2005 and smaller mean relative and absolute errors in 2007. Overall, the 2008 model has better accuracy and slightly better precision than the 2012 model.

Model Comparisons

Advantages and Disadvantages

Due to its mechanistic nature, WARMF 2012 is more suitable for simulating catchment-scale water quality management options to remediate the DO deficit in the Stockton DWSC. However, based on the results of this analysis, the WARMF 2012 model is not as accurate as WARMF 2008 and tends to under-predict loads, making it unconservative for the parameters that it underpredicts. The results of the Gowdy Output analysis suggest that WARMF 2012 and WARMF 2008 are inconsistent in how they simulate individual tributaries (Weissmann et al. 2013b). Thus, there is a need to better characterize individual tributaries and improve the calibration of the WARMF 2012 to improve its usefulness.

This analysis suggests that WARMF 2008 model has better accuracy and is thus currently more dependable than WARMF 2012 for representing loads and concentrations in the upper SJR watershed. Since the model contains fewer elements than WARMF 2012, it is easier to understand and may save time for simulations that do not need the extended functions of WARMF 2012. Due to the extensive use of boundary input files, WARMF 2008 is largely dependent on observed water quality and flow data and does not support scenarios for catchment-scale water quality management strategies as well as WARMF 2012. In addition, more flow and water quality data is needed both at upstream tributary boundaries for setting model initial conditions and at water quality stations along the SJR for model calibration and verification after September 30, 2007.

Recommendations

With improvements, both models have utility for analyzing the upper SJR watershed to help decision-makers understand the mechanisms of the DO deficit in the Stockton DWSC and analyze water quality management strategies to meet the DO regulatory standards. Regardless of the model utilized, more data collection will be needed for calibration and validation of future time periods to assess water quality management strategies and possibly to maintain compliance when it is achieved. Since modeling for adaptive management is an iterative process with changing goals, discretion should be applied when considering whether the desired improvement in model performance and functionality will be worthwhile for the amount of time and resources invested. Recommended functionality improvements include updates to the Flux Output, adding wetland simulation capabilities, and improving integration with the Link-Node model. In both versions of WARMF, the dependability of the Flux Output needs verification (Karpuzcu, personal communication). If this is confirmed and the ability to export results to a spreadsheet is added, it will make it easier to diagnose problems with the model calibration and understand reaction mechanisms. An upgrade to the model engine to incorporate the simulation of wetland hydraulics and kinetics would improve the model's utility for assessing water quality management strategies (Karpuzcu et al. 2013). Further integration with the Link-Node model to enable the Gowdy Output to analyze loads directly in the Stockton DWSC and enable the Flux Output to analyze the mass balance within the Stockton DWSC would be useful for better comprehension of constituent reaction mechanisms between the SJR at Vernalis and the Stockton DWSC.

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Table 1. Coefficient of determination (R^2) values between loads calculated from grab sample data and loads calculated from WARMF 2012 and 2008 model output from January 1, 2005 through September 30, 2007 in the San Joaquin River at Vernalis from January 1, 2005 through September 30, 2007.

	WARMF 2012	WARMF 2008
NO_3 - N	0.275	0.367
TAN	0.799	0.661
Org N	0.854	0.871
TN	0.785	0.782
BOD	0.508	0.646
TDS	0.594	0.752
Total Phytoplankton (chl)	0.426	0.502
PO_4 - P	0.836	0.861
TP	0.924	0.94
DOC	0.829	0.95

Table 2. Summary statistics for observed and simulated loads in the San Joaquin River at Vernalis using the WARMF 2012 and 2008 model from January 1, 2005 through September 30, 2007.

		NO_3-N	TAN	Org N	TN	BOD
Observed	**Number of Points**	67	67	65	65	59
	Mean (kg d^{-1}) (alt. lb d^{-1})	8,740 (19,273)	657 (1,449)	4,836 (10,664)	13,848 (30,534)	40,680 (89,699)
	Min (kg d^{-1}) (alt. lb d^{-1})	3,384 (7,462)	18.9 (41.7)	65.7 (145)	4,249 (9,369)	5,998 (13,225)
	Max (kg d^{-1}) (alt. lb d^{-1})	22,721 (50,099)	5,662 (12,485)	42,050 (92,721)	64,678 (142,616)	237,855 (524,471)
	Std. Dev. (kg d^{-1}) (alt. lb d^{-1})	3,951 (8,711)	1,108 (2,442)	6,602 (14,556)	9,206 (20,298)	44,228 (97,523)
WARMF 2012	**Number of Points**	71	71	71	71	71
	Mean (kg d^{-1}) (alt. lb d^{-1})	6,127 (13,509)	837 (1,846)	6,623 (14,603)	13,586 (29,958)	20,045 (44,200)
	Min (kg d^{-1}) (alt. lb d^{-1})	2,829 (6,238)	55.4 (122)	1,359 (2,996)	4,253 (9,378)	2,385 (5,259)
	Max (kg d^{-1}) (alt. lb d^{-1})	23,730 (52,324)	5,339 (11,773)	78,496 (173,083)	107,565 (237,180)	216,543 (477,477)
	Std. Dev. (kg d^{-1}) (alt. lb d^{-1})	3,589 (7,914)	951 (2,098)	10,210 (22,514)	13,613 (30,018)	34,183 (75,373)
WARMF 2008	**Number of Points**	71	71	71	71	71
	Mean (kg d^{-1}) (alt. lb d^{-1})	9,704 (21,398)	967 (2,132)	5,938 (13,094)	16,609 (36,624)	20,210 (44,562)
	Min (kg d^{-1}) (alt. lb d^{-1})	4,519 (9,965)	128 (282)	740 (1,632)	5,644 (12,445)	5,125 (11,300)
	Max (kg d^{-1}) (alt. lb d^{-1})	27,172 (59,915)	5,263 (11,605)	47,575 (104,902)	79,395 (175,066)	114,401 (252,255)
	Std. Dev. (kg d^{-1}) (alt. lb d^{-1})	4,777 (10,534)	932 (2,056)	7,441 (16,408)	11,715 (25,831)	21,863 (48,208)

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		TDS	Total Phytoplankton	PO4-P	TP	DOC
Observed	**Number of Points**	71	69	67	65	66
	Mean (kg d-1) (alt. lb d-1)	2,409,205 (5,312,297)	244 (539)	1,054 (2,323)	1,887 (4,160)	47,422 (104,566)
	Min (kg d-1) (alt. lb d-1)	714,585 (15,75,661)	23.7 (52.2)	13.1 (28.8)	320 (706)	6,158 (13,579)
	Max (kg d-1) (alt. lb d-1)	6,831,650 (15,063,788)	1,164 (2,566)	7,424 (16,369)	20,567 (45,351)	348,299 (767,998)
	Std. Dev. (kg d-1) (alt. lb d-1)	1,316,756 (2,903,447)	211 (464)	1,366 (3,011)	2,783 (6,137)	66,408 (146,430)
WARMF 2012	**Number of Points**	71	71	67	67	67
	Mean (kg d-1) (alt. lb d-1)	2,242,179 (4,944,005)	186 (410)	566 (1,248)	1,526 (3,364)	49,869 (109,961)
	Min (kg d-1) (alt. lb d-1)	31,432 (69,308)	4.33 (9.6)	-38 (-83.7)	217 (479)	8,587 (18,935)
	Max (kg d-1) (alt. lb d-1)	11,379,444 (25,091,673)	1,883 (4,152)	4,656 (10,266)	21,665 (47,771)	619,282 (1,365,517)
	Std. Dev. (kg d-1) (alt. lb d-1)	1,812,361 (3,996,255)	398 (878)	745 (1,642)	2,695 (5,943)	84,973 (187,365)
WARMF 2008	**Number of Points**	71	71	67	67	67
	Mean (kg d-1) (alt. lb d-1)	2,267,060 (4,998,868)	223 (491)	1,151 (2,538)	2,329 (5,136)	45,682 (100,728)
	Min (kg d-1) (alt. lb d-1)	638,543 (1,407,988)	17.2 (38)	255 (562)	472 (1,041)	5,189 (11,442)
	Max (kg d-1) (alt. lb d-1)	8,000,216 (17,640,477)	829 (1,828)	8,673 (19,123)	21,804 (48,078)	421,935 (930,366)
	Std. Dev. (kg d-1) (alt. lb d-1)	1,600,013 (3,528,029)	168 (370)	1,336 (2,946)	3,001 (6,617)	71,530 (157,724)

Table 3. Mean relative and absolute error for loads in the San Joaquin River at Vernalis calculated using concentration and flow results from WARMF 2012 and 2008 from January 1, 2005 through September 30, 2007.

		NO_3^--N	**TAN**	**Org N**	**TN**	**BOD**	**TDS**
WARMF 2012	Mean Relative Error (kg d^{-1}) (alt. lb d^{-1})	-2,598 (-5,729)	200 (442)	1,775 (3,913)	-450 (-992)	-18,185 (-40,099)	-167,026 (-368,292)
	Mean Absolute Error (kg d^{-1}) (alt. lb d^{-1})	3,522 (7,765)	367 (810)	2,531 (5,581)	4,663 (10,283)	20,924 (46,137)	761,659 (1,679,457)
	Mean Relative Error %	-30%	31%	37%	-3.20%	-45%	-6.90%
	Mean Absolute Error %	40%	56%	52%	34%	51%	32%
WARMF 2008	Mean Relative Error (kg d^{-1}) (alt. lb d^{-1})	891 (1,965)	310 (684)	946 (2,087)	2,032 (4,480)	-18,643 (-41,107)	-142,144 (-313,428)
	Mean Absolute Error (kg d^{-1}) (alt. lb d^{-1})	2,766 (6,099)	504 (1,112)	1,855 (4,090)	3,947 (8,704)	19,820 (43,703)	562,622 (1,240,582)
	Mean Relative Error %	10%	47%	20%	15%	-46%	-5.90%
	Mean Absolute Error %	32%	77%	38%	29%	49%	23%

(Continued on the next page)

(Table 3 continued from the previous page)

		Total Phytoplankton (chl)	**PO4 P**	**TP**	**DOC**
WARMF 2012	Mean Relative Error (kg d 1) (alt. lb d 1)	-57 (-126)	-488 (-1,075)	-401 (-884)	2,835 (6,252)
	Mean Absolute Error (kg d 1) (alt. lb d 1)	203 (447)	496 (1,094)	552 (1,218)	13,864 (30,571)
	Mean Relative Error %	-23%	-46%	-21%	6.00%
	Mean Absolute Error %	83%	47%	29%	29%
WARMF 2008	Mean Relative Error (kg d 1) (alt. lb d 1)	-18 (-38.7)	97.4 (215)	347 (765)	-1,402 (-3,090)
	Mean Absolute Error (kg d 1) (alt. lb d 1)	98 (217)	306 (674)	578 (1,274)	9,438 (20,810)
	Mean Relative Error %	-7%	9%	18%	-3%
	Mean Absolute Error %	40%	29%	31%	20%

Table 4. Sum of mean relative error and mean absolute error percentages by year between observed and simulated constituent concentrations using the WARMF 2012 and 2008 model in the San Joaquin River at Vernalis from January 1, 2005 to September 30, 2007. All constituents (NO_3-N, TAN, TN, BOD, TDS, total phytoplankton (chl), PO_4-P, TP, and DOC) were included except for Org-N since it was calculated from TN, NO_3-N, and TAN loads.

	Sum of WARMF 2012 Mean Relative Error %	**Sum of WARMF 2008 Mean Relative Error %**	**Sum of WARMF 2012 Mean Absolute Error %**	**Sum of WARMF 2008 Mean Absolute Error %**
2005	-227%	77%	465%	439%
2006	-106%	15%	556%	378%
2007	-113%	35%	234%	215%

Figure 1. Overview of the WARMF 2008 model domain. Yellow catchments are included in the model domain for simulating the San Joaquin River between Old River (River 319) and Stevinson (River 752).

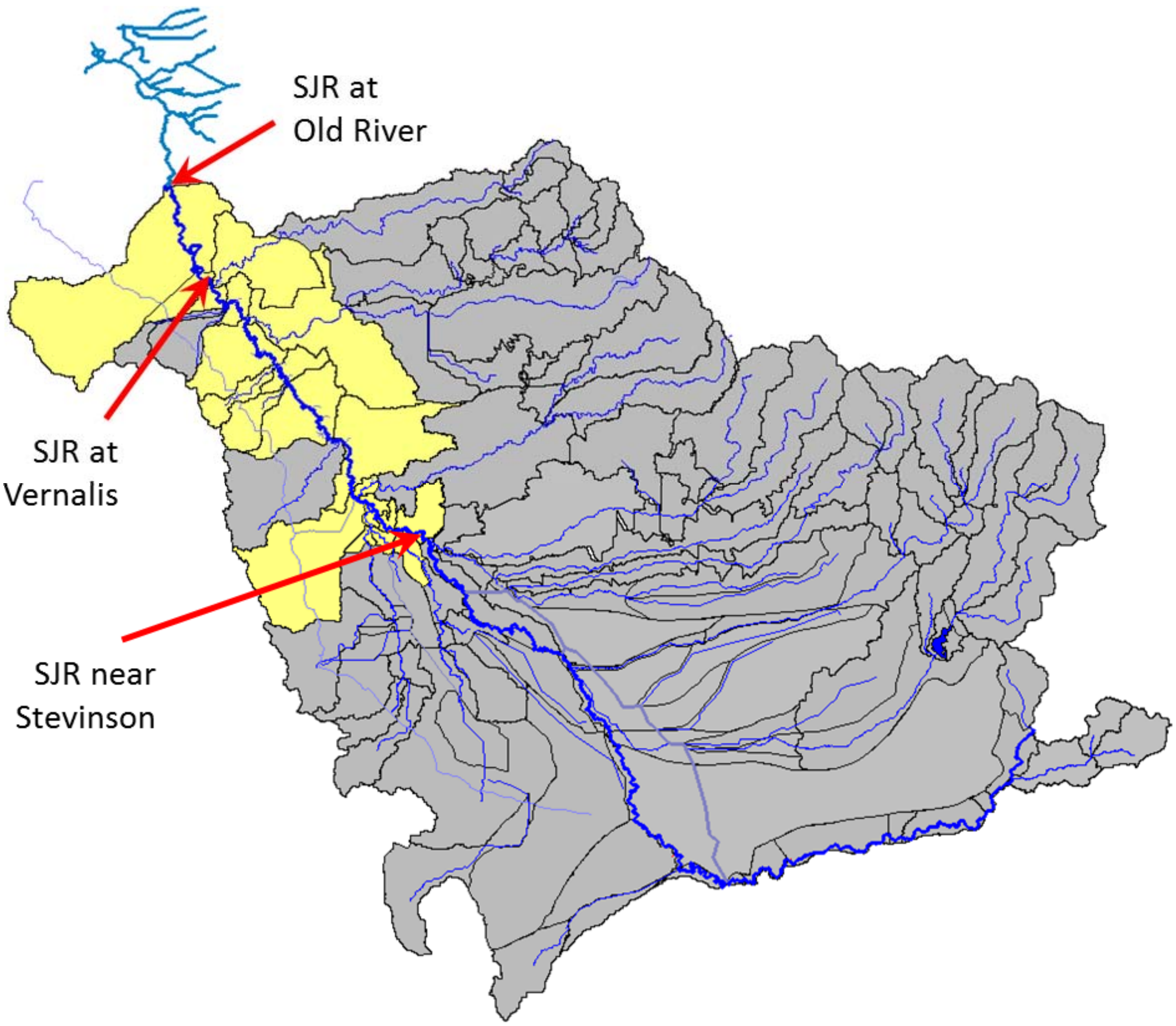


Figure 2. Overview of updates to the WARMF model domain between 2008 and 2012 from individual projects (Herr, Chen, and van Werkhoven 2008; Larry Walker Associates, et al. 2009; USBR 2012a; USBR 2012b; Systech 2011; Systech 2012; Systech 2013).

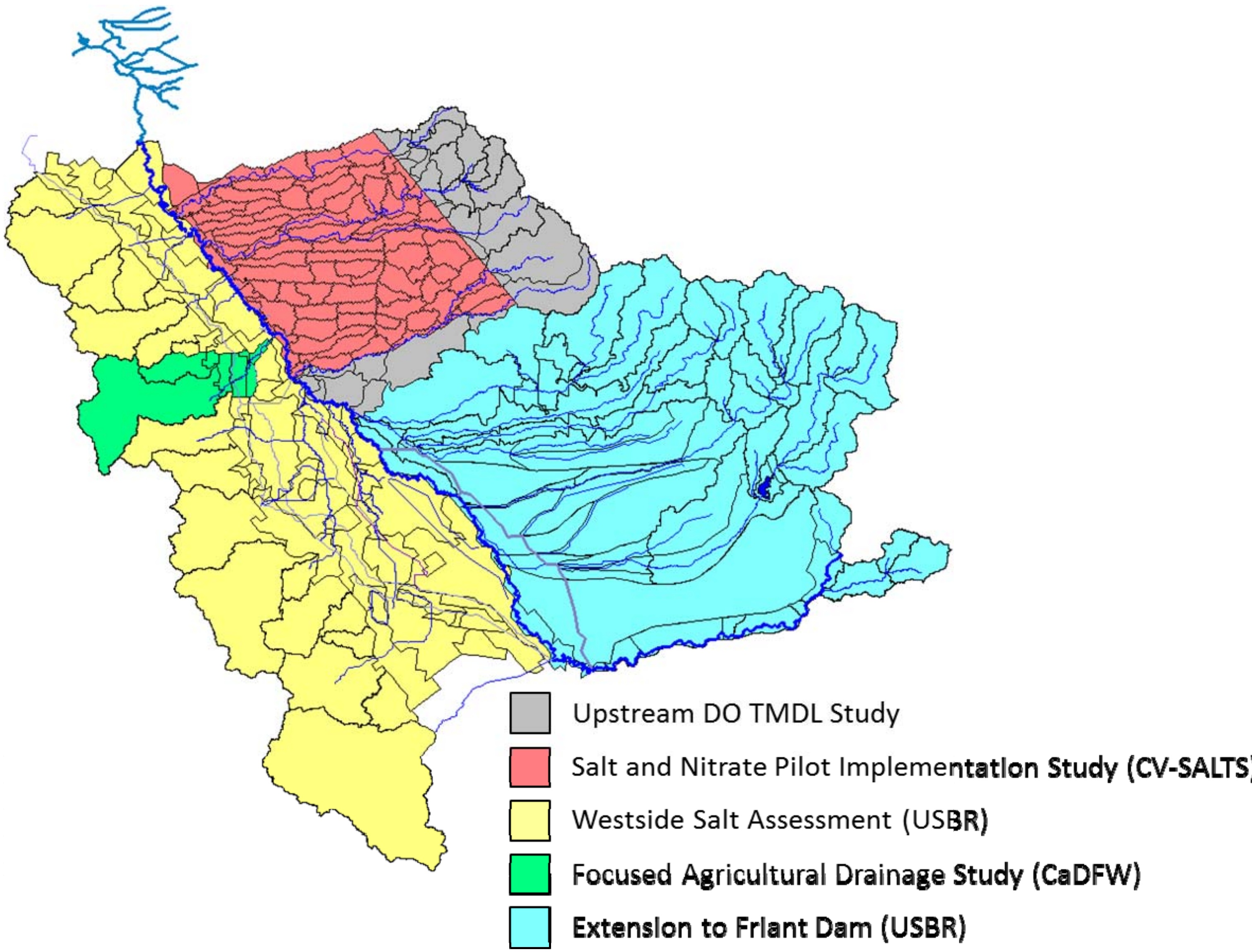


Figure 3. Overview of the WARMF 2012 model domain. Yellow catchments are included in the model domain for simulating the San Joaquin River between Old River and at the Millerton Lake Tailwater (Systech 2011; Systech 2012).

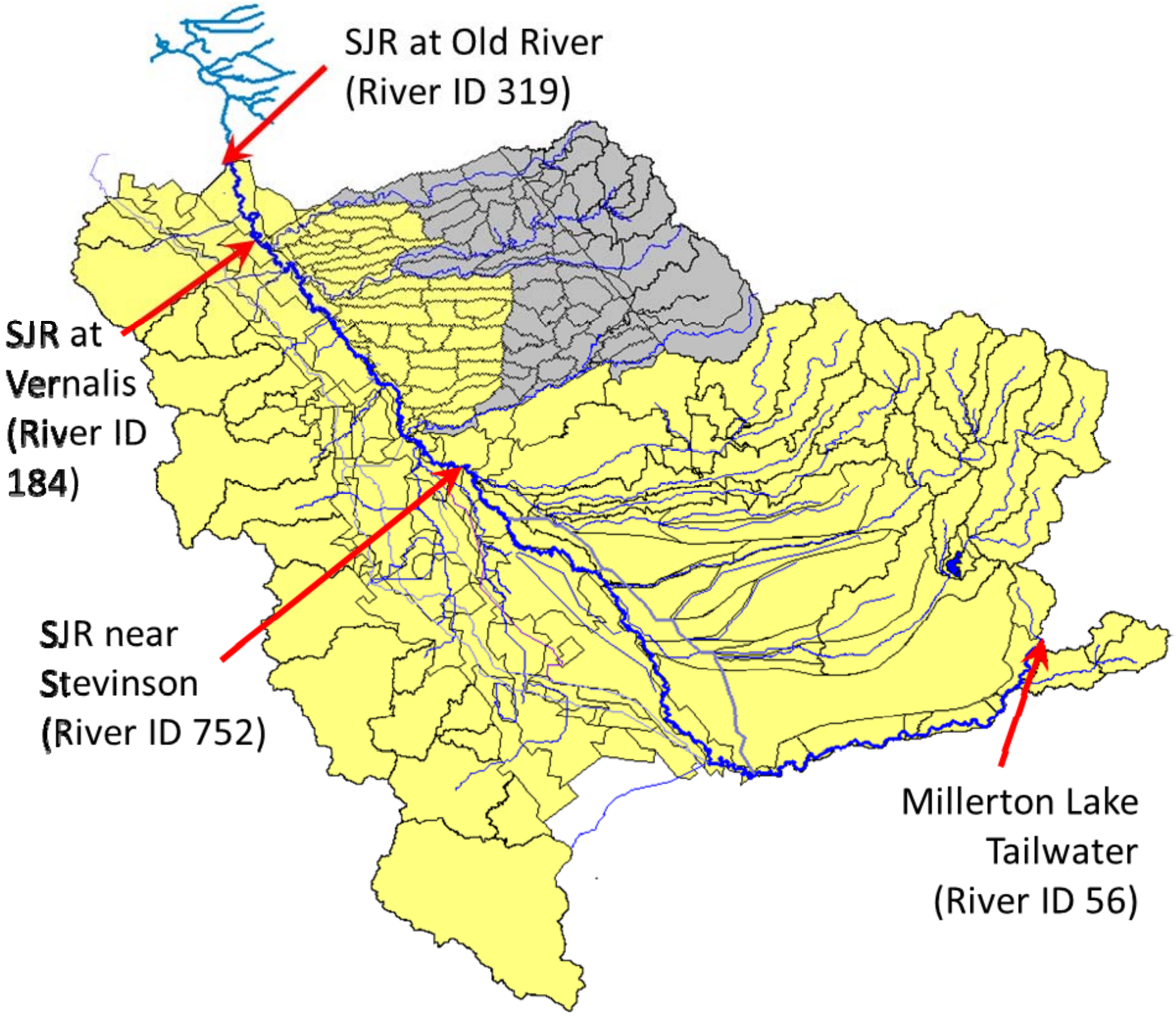


Figure 4. Demonstration difference between accuracy and precision. Accuracy describes the tendency of the model to underpredict or overpredict the observed data while precision describes the ability of the model to match the pattern of the data. Relative error and absolute error are two methods to measure accuracy and precision respectively.

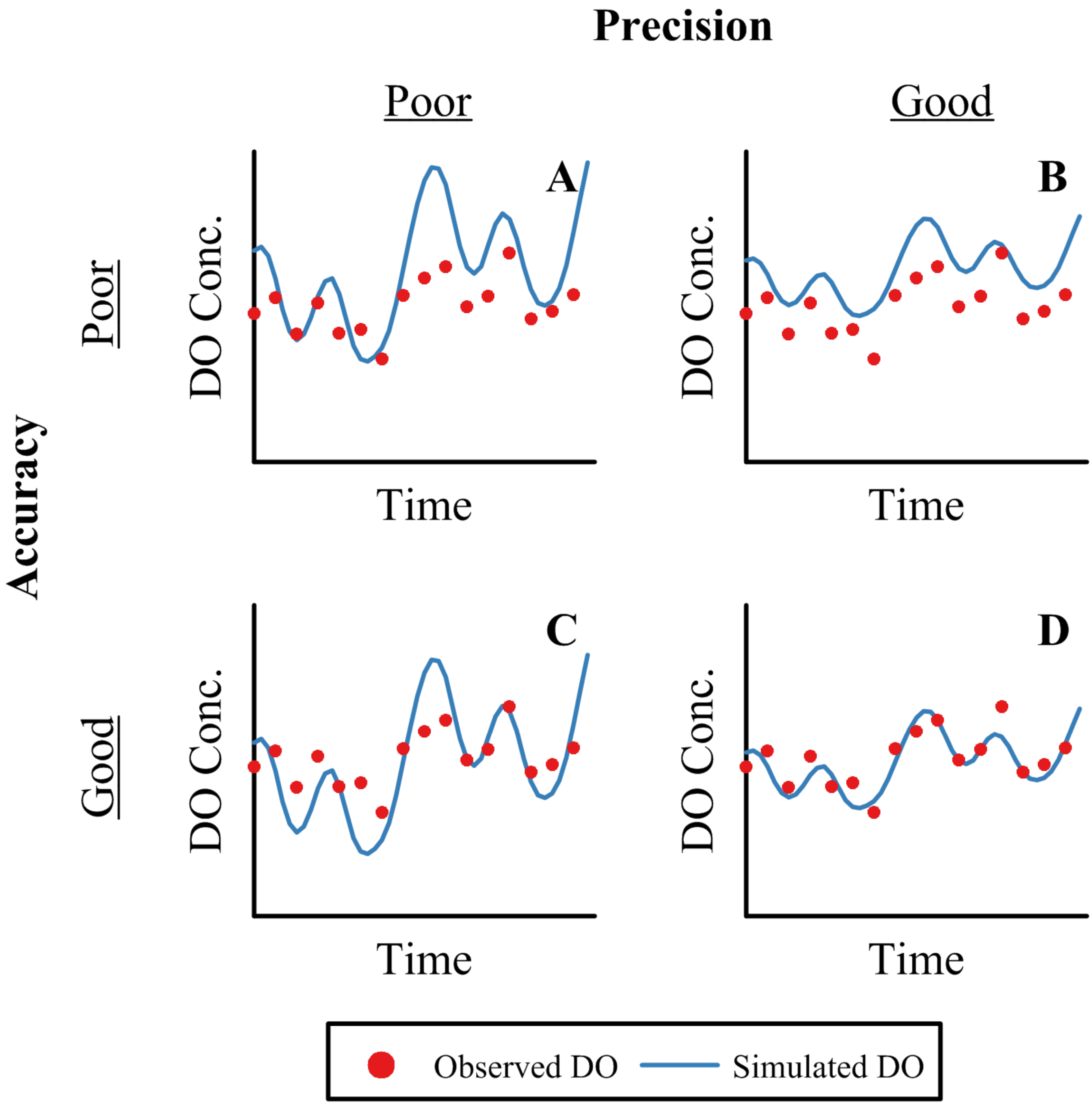
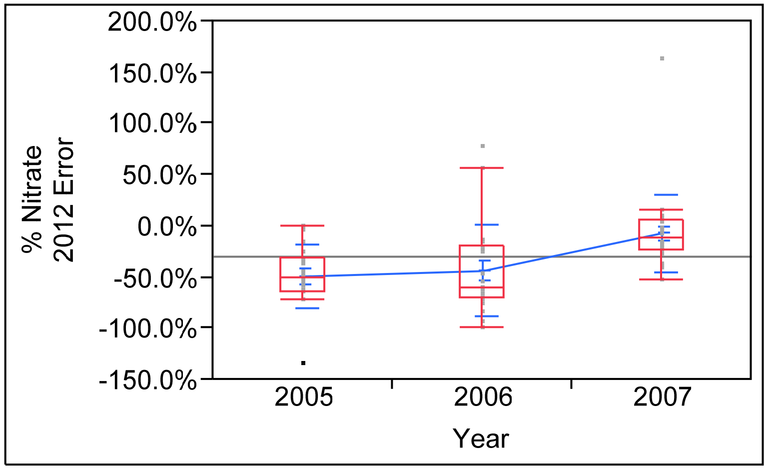


Figure 5. Mean relative error analysis for NO_3-N by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



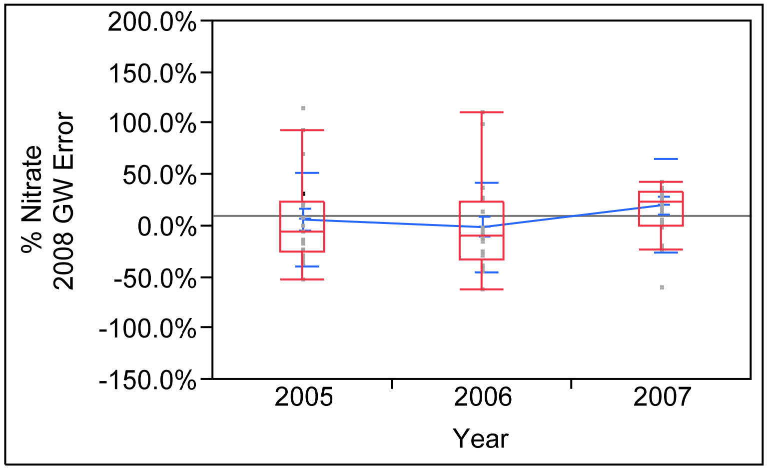
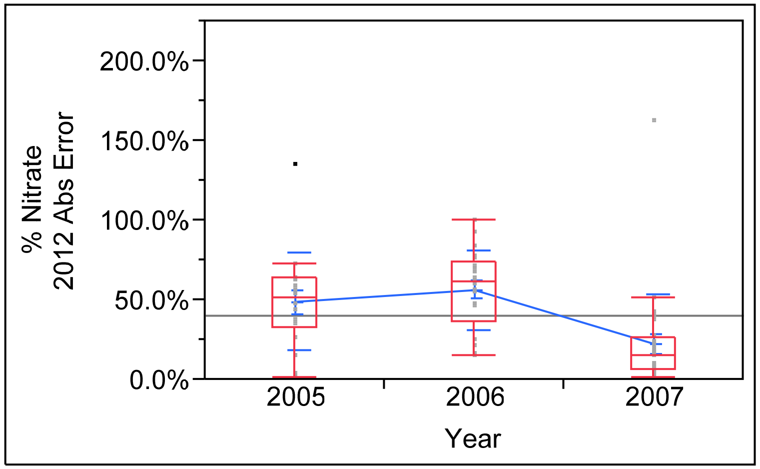


Figure 6. Mean absolute error analysis for NO_3-N by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



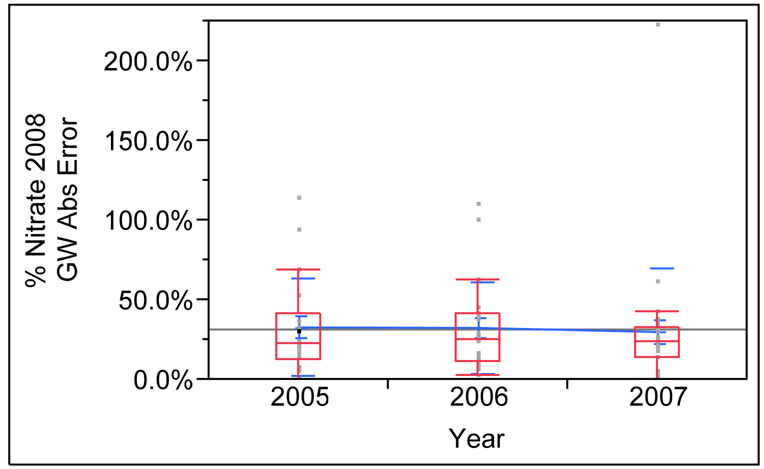
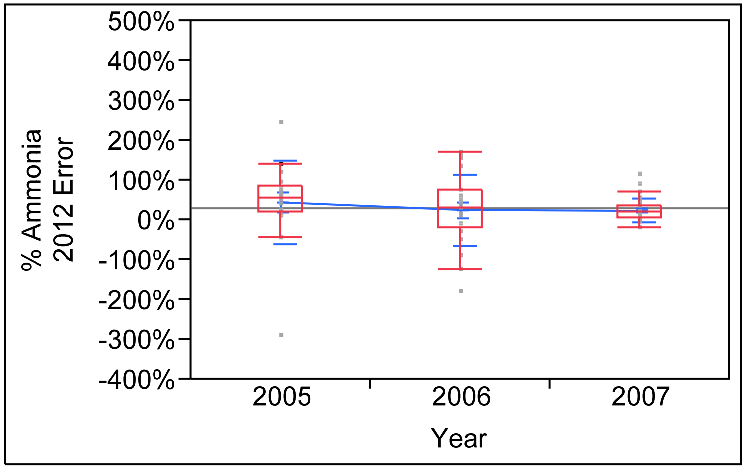


Figure 7. Mean relative error analysis for TAN by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



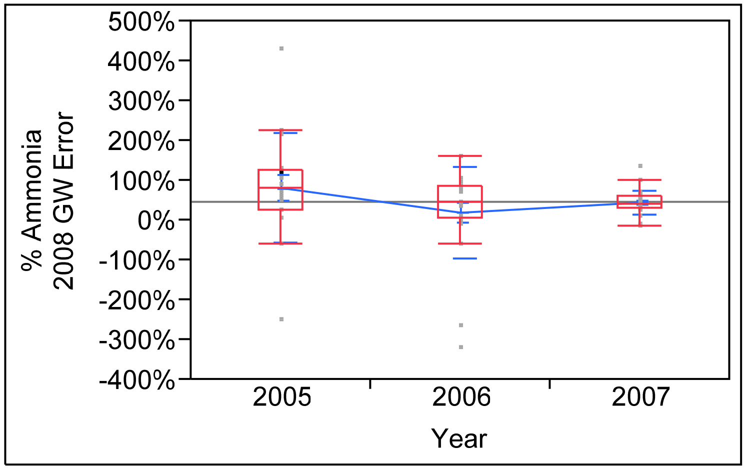
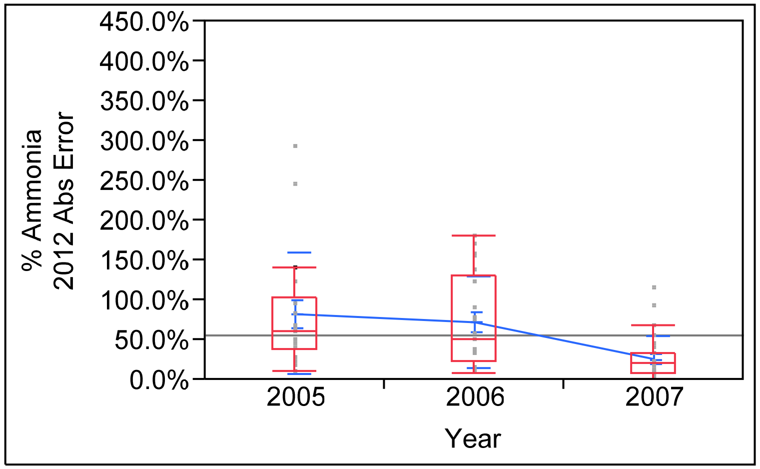


Figure 8. Mean absolute error analysis for TAN by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



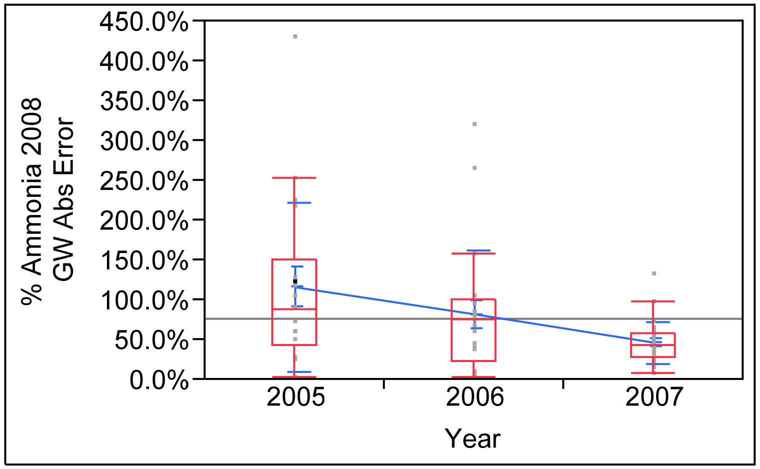
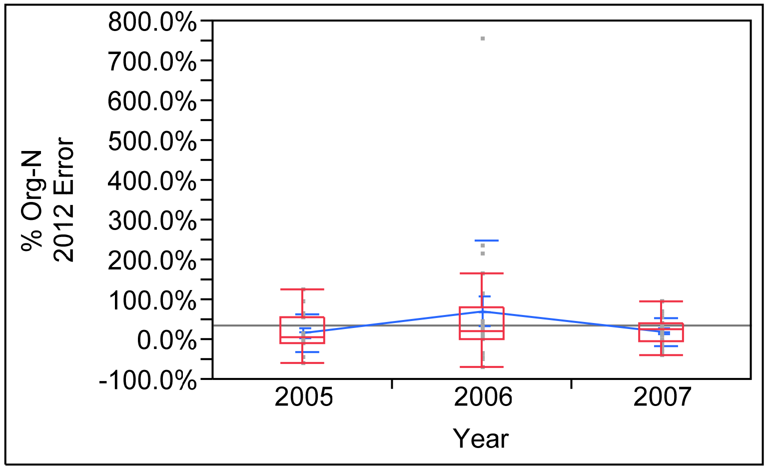


Figure 9. Mean relative error analysis for Org-N by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



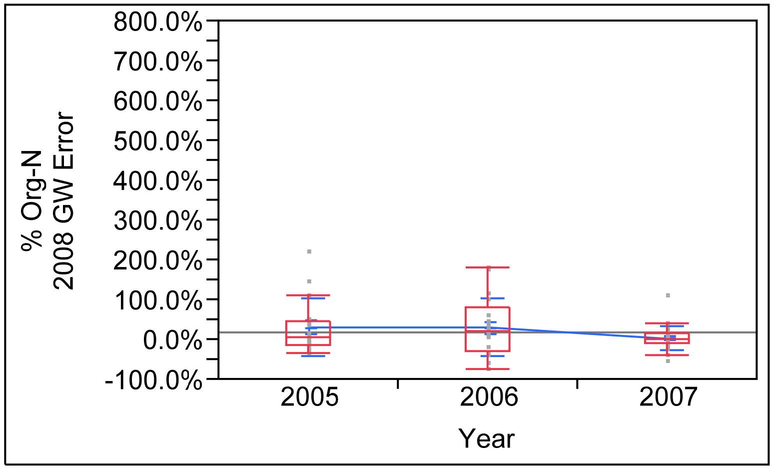
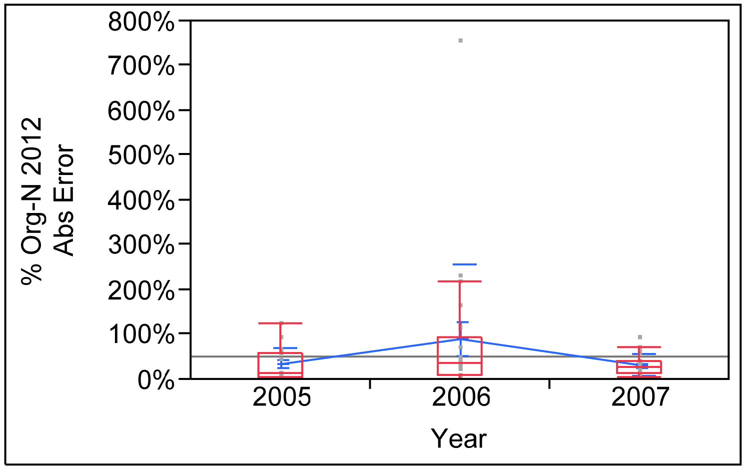


Figure 10. Mean absolute error analysis for Org-N by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



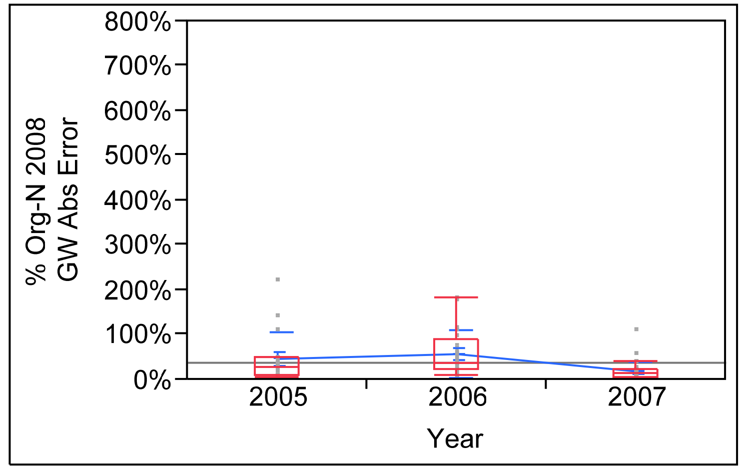


Figure 11. Mean relative error analysis for TN by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

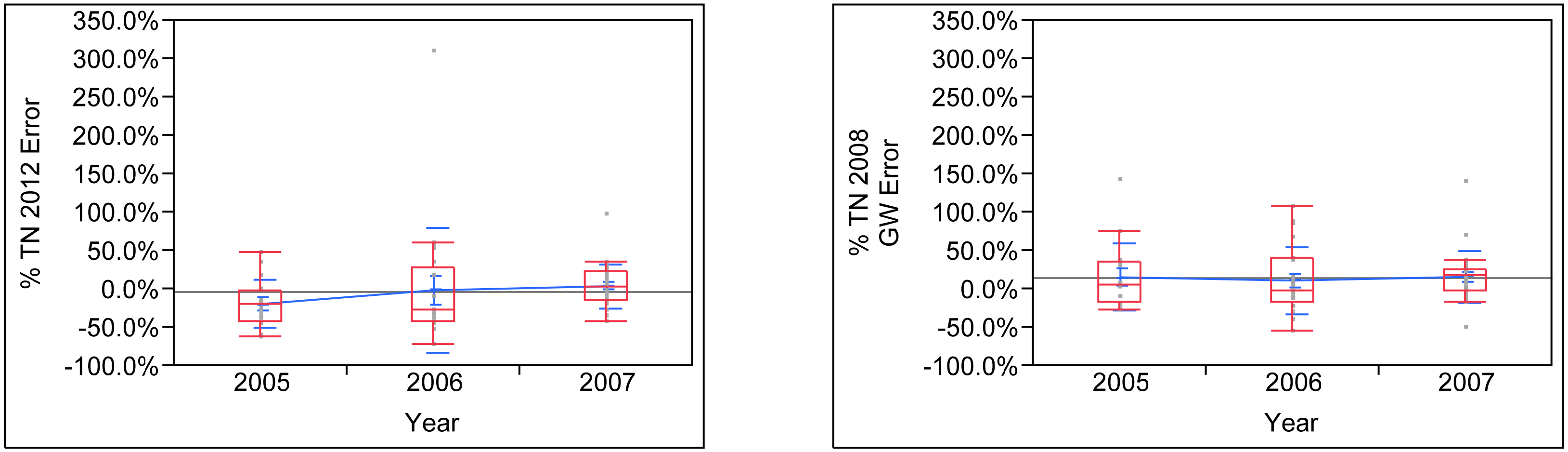


Figure 12. Mean absolute error analysis for TN by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

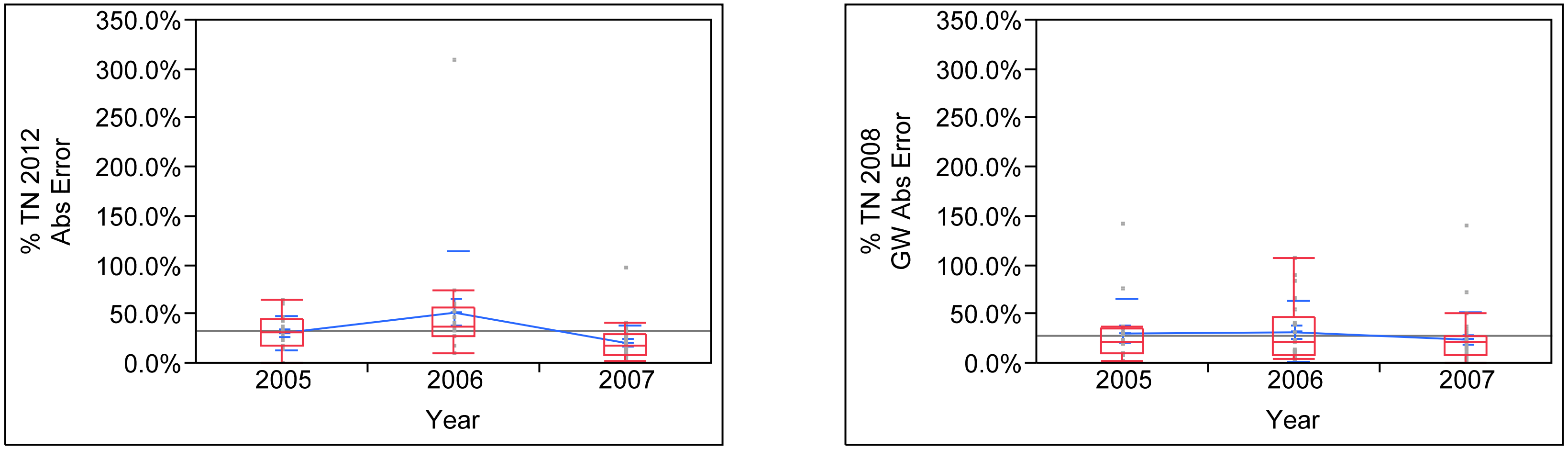


Figure 13. Mean relative error analysis for BOD by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

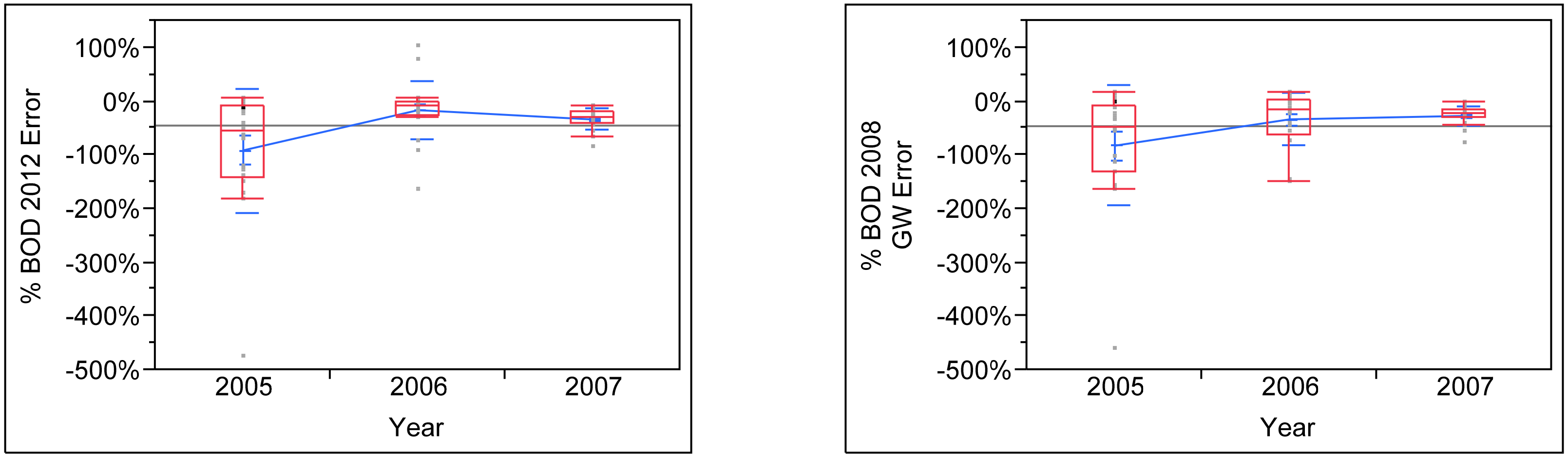
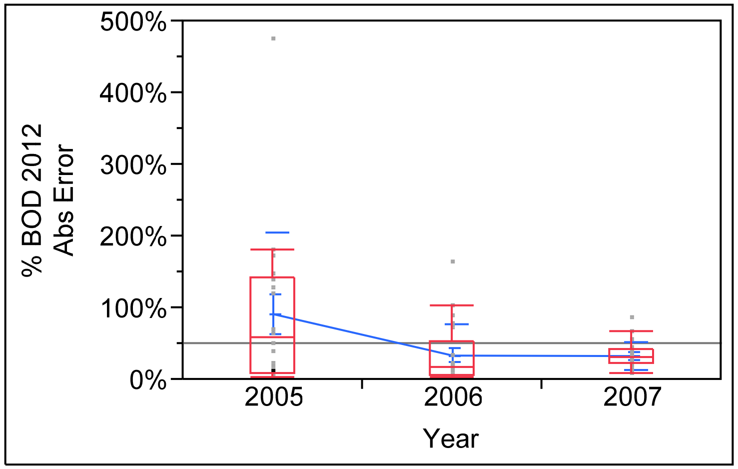


Figure 14. Mean absolute error analysis for BOD by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



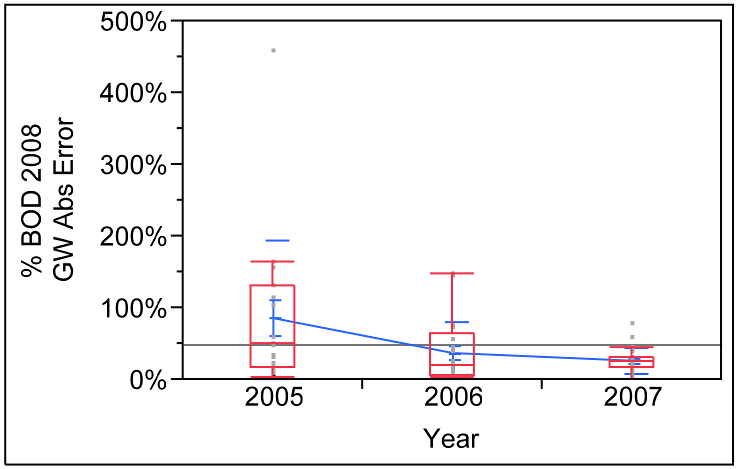


Figure 15. Mean relative error analysis for TDS by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

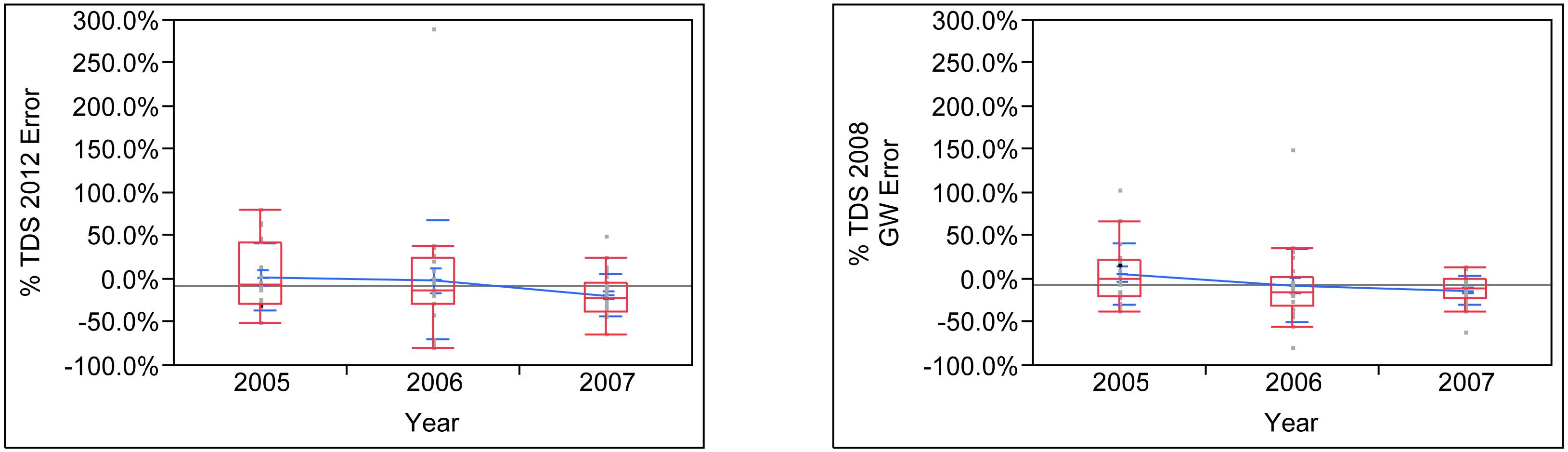
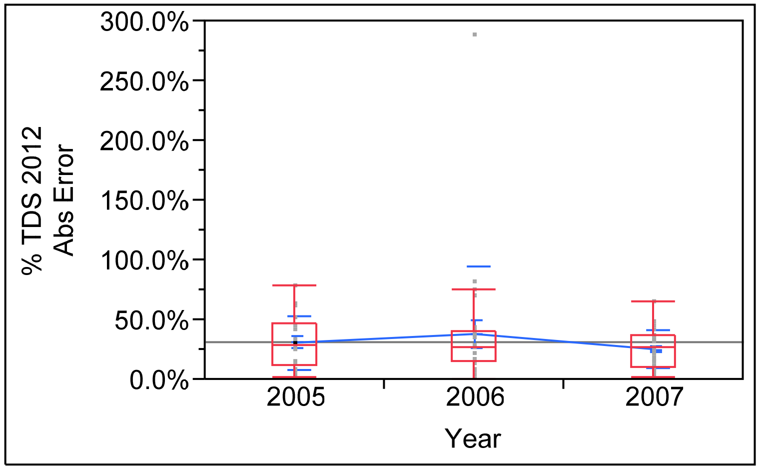


Figure 16. Mean absolute error analysis for TDS by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



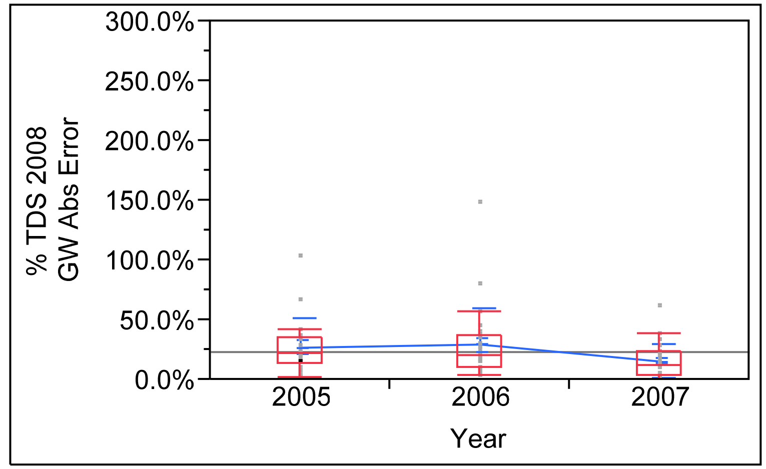
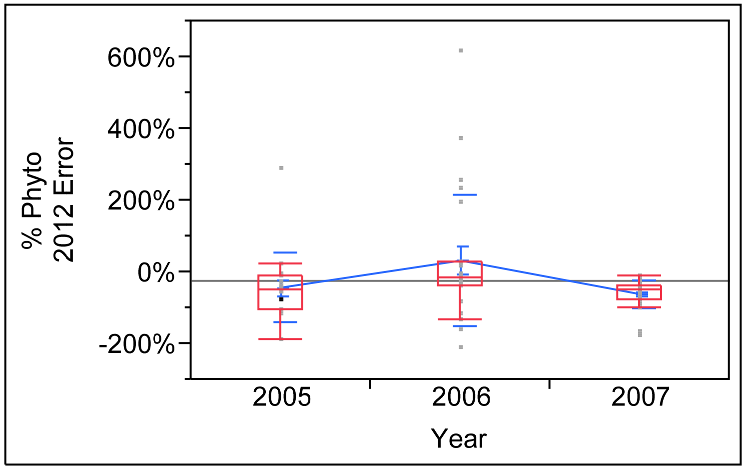


Figure 17. Mean relative error analysis for total phytoplankton by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



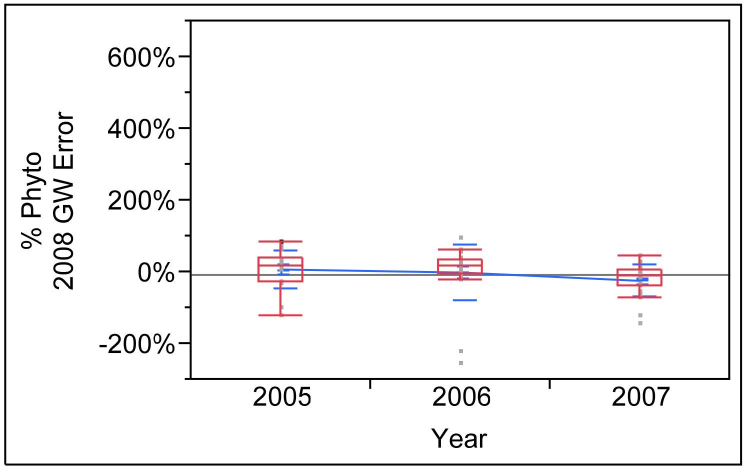


Figure 18. Mean absolute error analysis for total phytoplankton by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

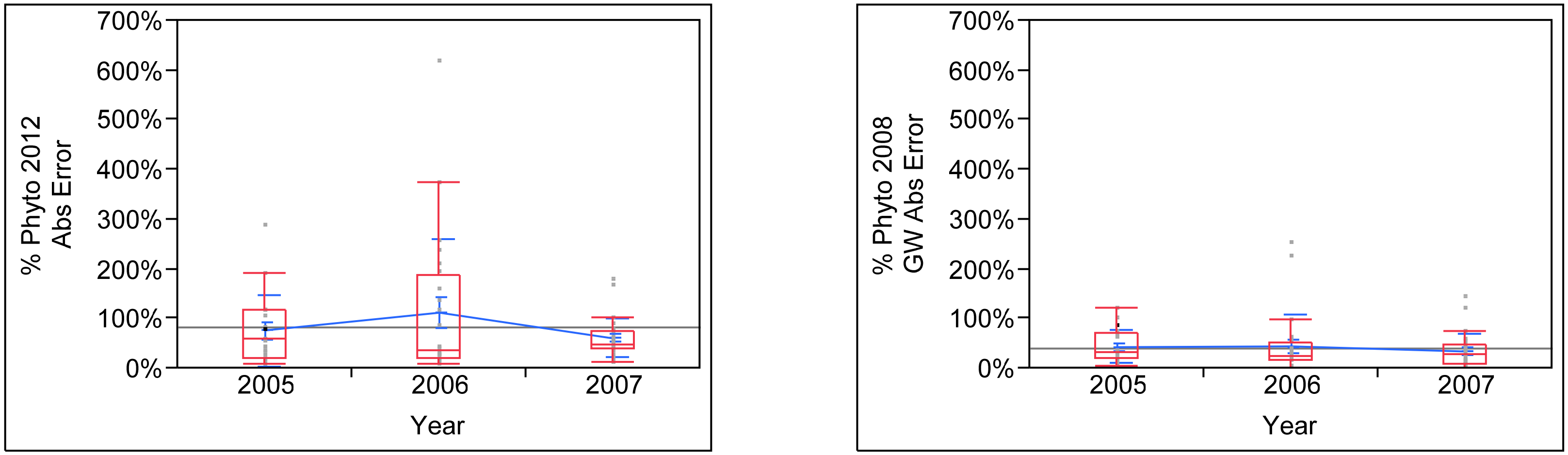
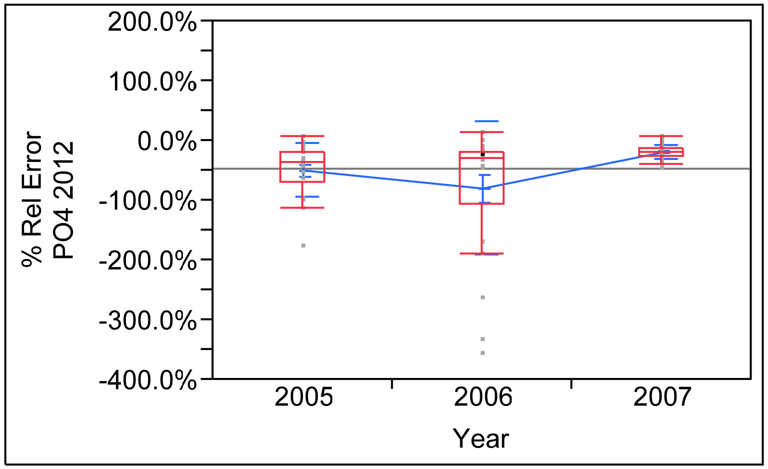


Figure 19. Mean relative error analysis for PO_4-P by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



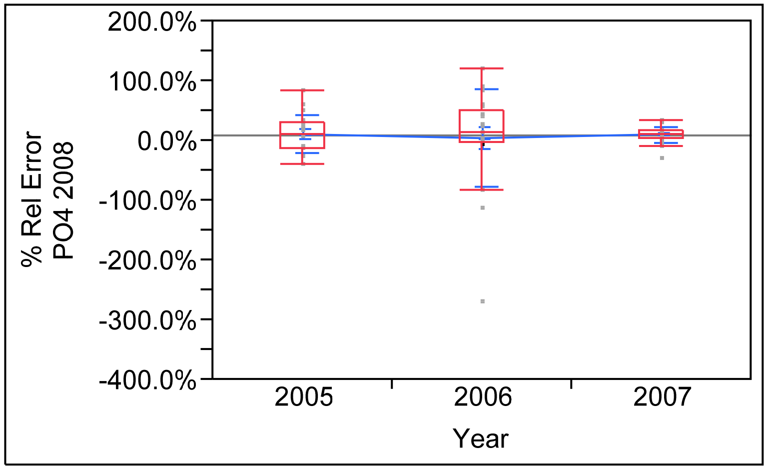


Figure 20. Mean absolute error analysis for PO_4-P by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

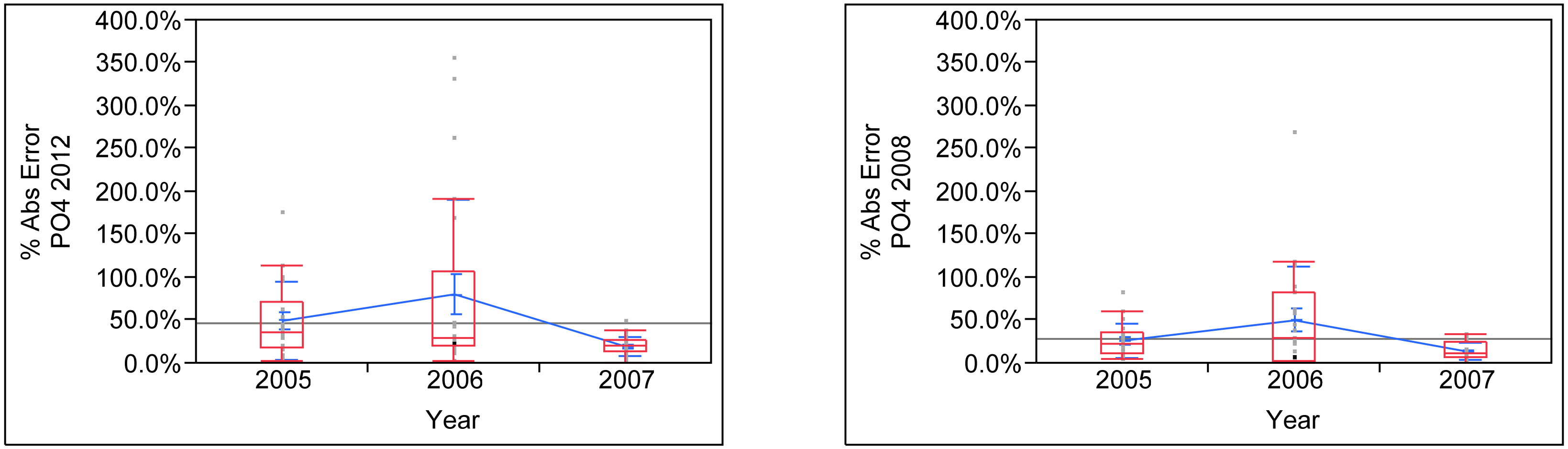


Figure 21. Mean relative error analysis for TP by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

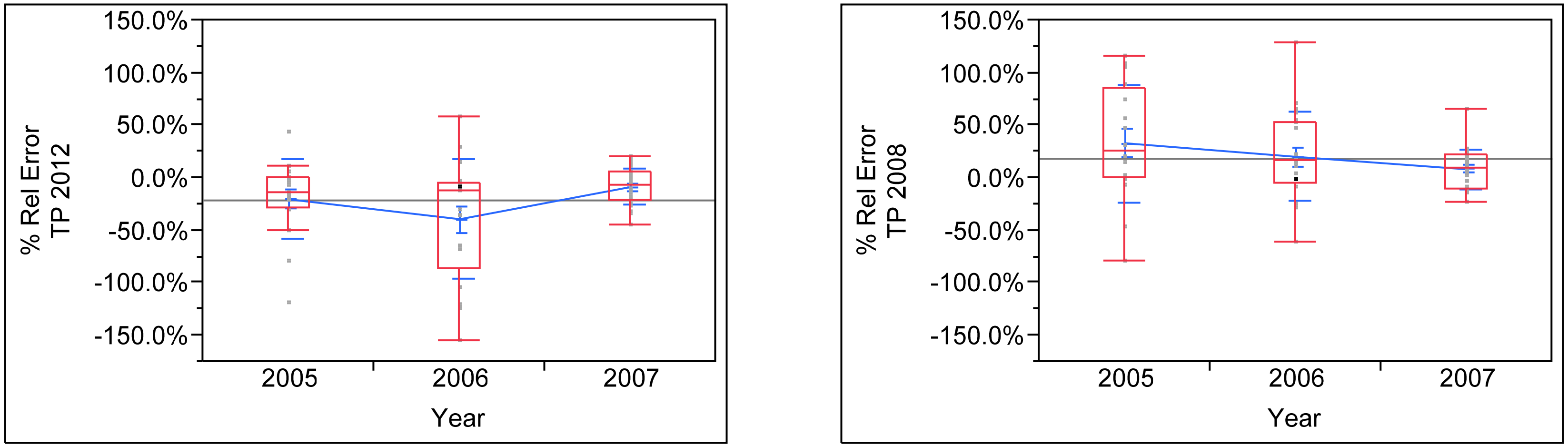
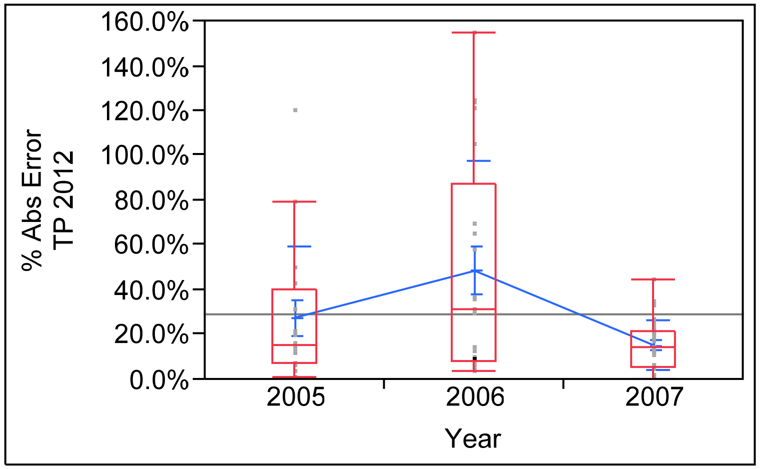


Figure 22. Mean absolute error analysis for TP by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.



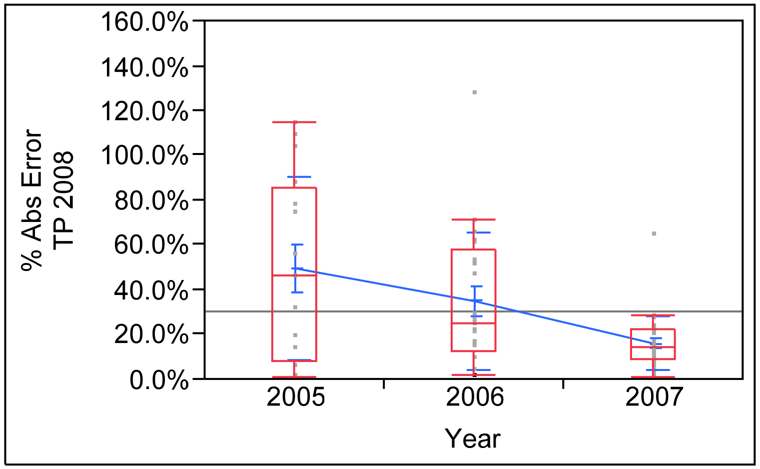


Figure 23. Mean relative error analysis for DOC by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.

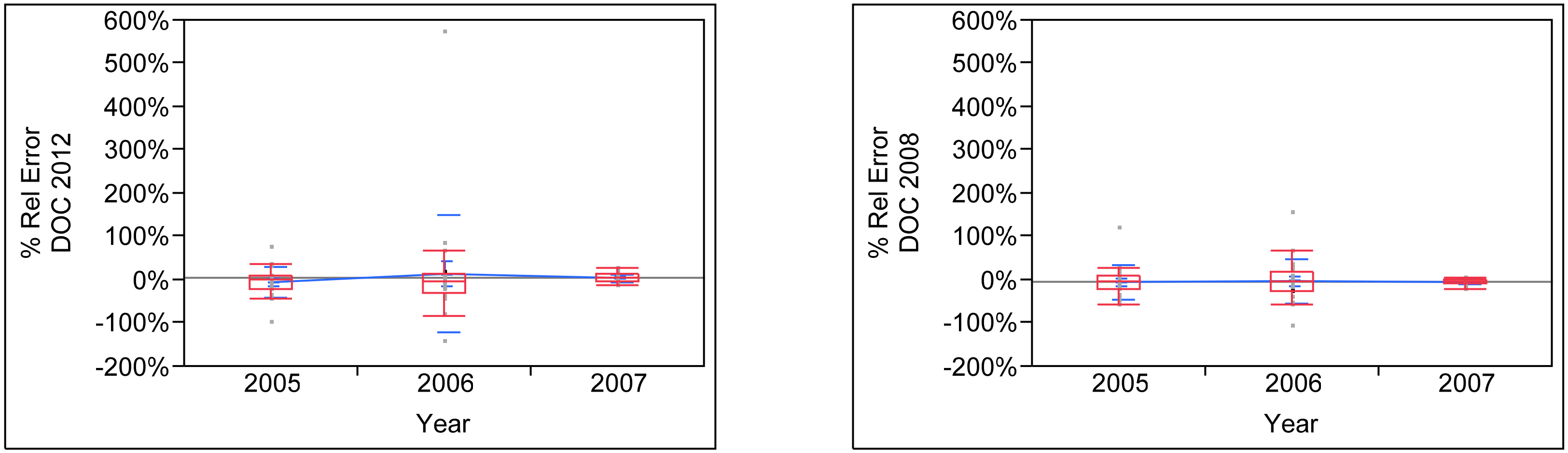


Figure 24. Mean absolute error analysis for DOC by year calculated using the WARMF 2012 and 2008 models between January 1, 2005 through September 30, 2007.